
Understanding Power Supply Application – Industrial and Medical Perspectives

Presented by Emerson Network Power

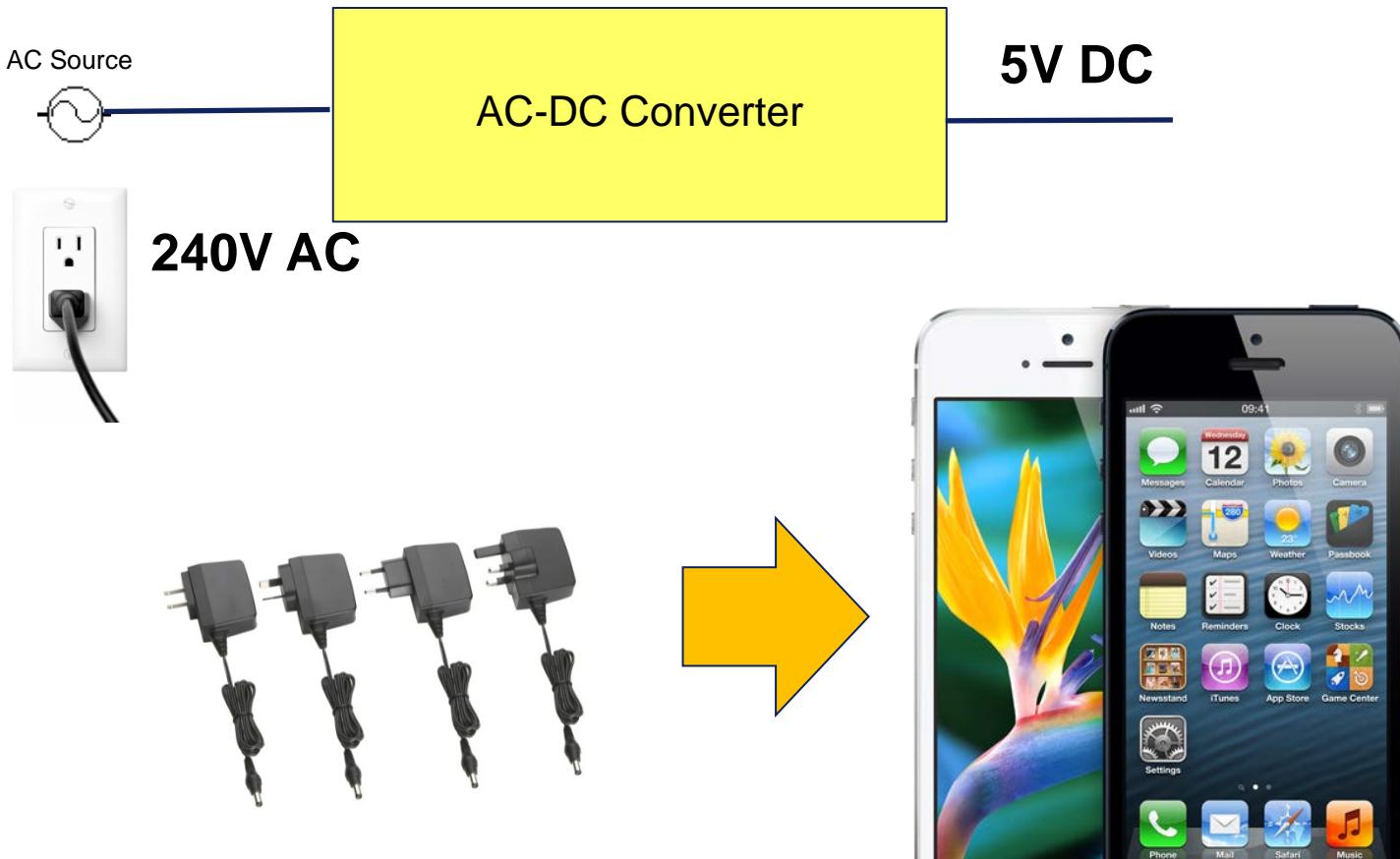
Understanding Power Supply Application

Topics

- What is a power supply
- Power supply common terminologies
- AC/DC power supply basic block diagram
- Output load characteristic
- Output voltage setting and adjustment
- Over voltage protection
- Over current protection
- Connect power supply outputs in series
- Connect power supply outputs in parallel
- Sense lines – when and how to connect them
- Inhibit/Enable control
- Output ripple reduction techniques
- Life vs MTBF
- Intelligent control
- Configurable power supply

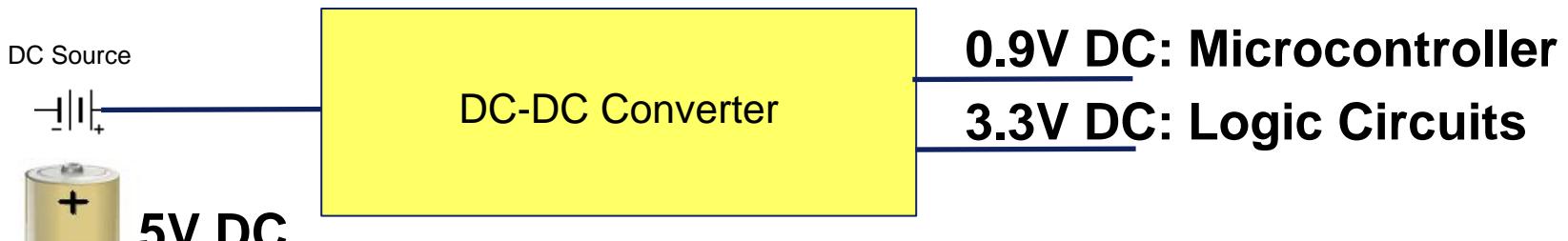
What is a Power Supply (AC-DC)?

- A power supply is a component that converts electricity to a useable form



What is a Power Supply (DC-DC)?

- A power supply is a component that converts electricity to a useable form

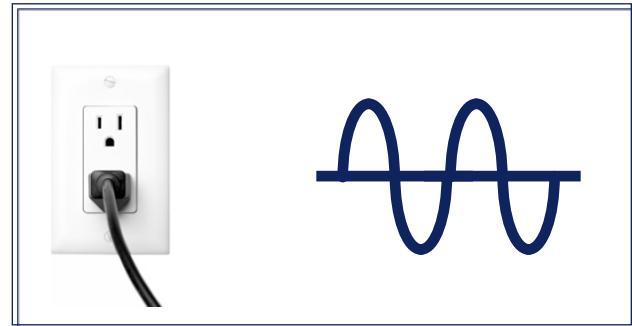


Power Supply Common Terminologies

- **AC Voltage**

- The power source you get from the wall outlet
- Typically 100VAC – 240VAC
- Typically 50-60Hz

AC Source



- **DC Voltage**

- What most of the components require to make them work
- Typically 1.5VDC – 48VDC

DC Source



Power Supply Common Terminologies

- **Line Regulation**

- Variation in the output voltage as the input voltage is varied between specified limits (Min to Max)

- **Load Regulation**

- Variation in the output voltage as the load is varied between specified limits
 - May be specified at a particular V_{in} i.e. nominal

- **Total Regulation**

- Sum of line and load regulation in addition to the initial output voltage accuracy of the unit, often including transient response
 - Worst case condition over operating temperature range and product lifetime

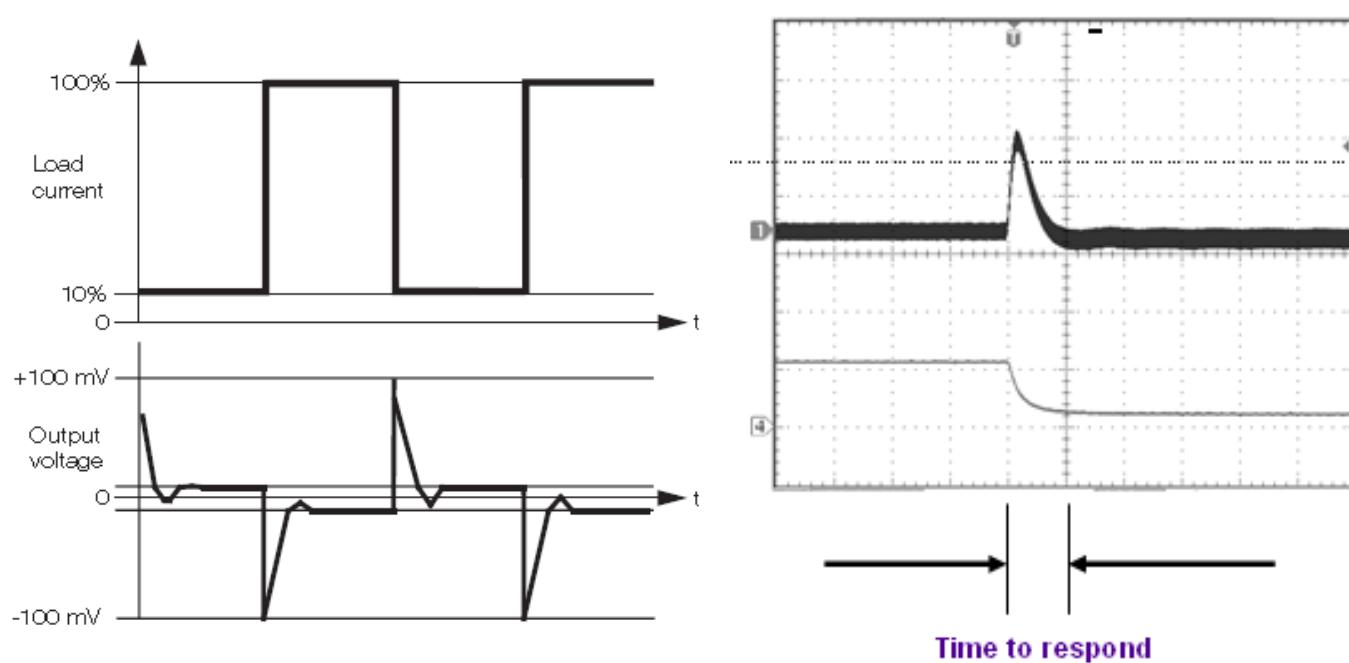


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Power Supply Common Terminologies

- **Transient (Dynamic) Response**

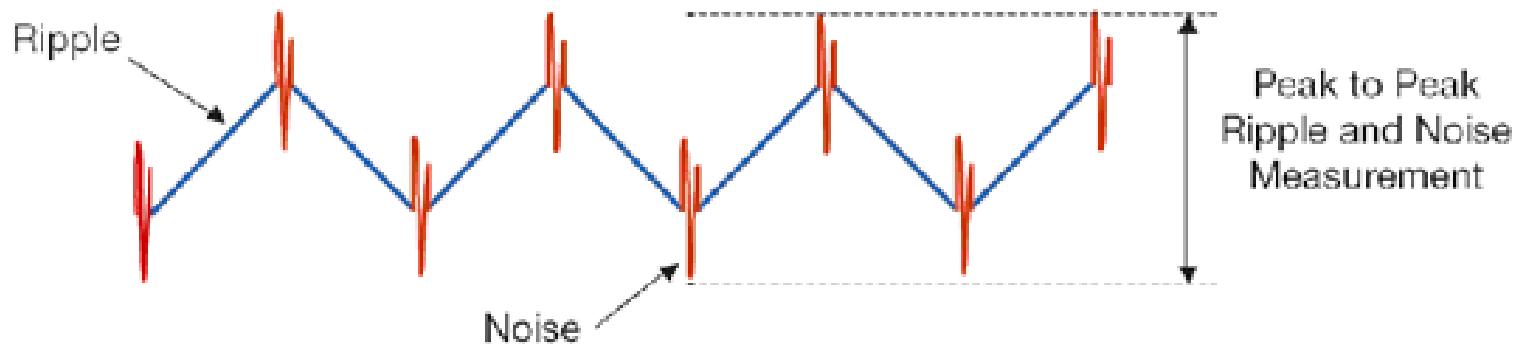
- Transient response measures how quickly and effectively the power supply can adjust to sudden changes in current demand. The figure below shows the behavior of a typical converter during a load-current transient and the resultant output voltage waveform.



Power Supply Common Terminologies

- **Output Ripple and Noise**

- The Ripple & Noise is sometimes referred to as Periodic And Random Disturbances or PARD.
- The following drawing shows how ripple and noise may look when viewed on an oscilloscope that is attached to the output of a typical switch mode power supply.



Power Supply Common Terminologies

- **Efficiency**

- The ratio between power available at the output and that consumed at the input of a power supply, usually stated in percent
- Efficiency = $P_{out} (W) / P_{in} (W) \times 100\%$

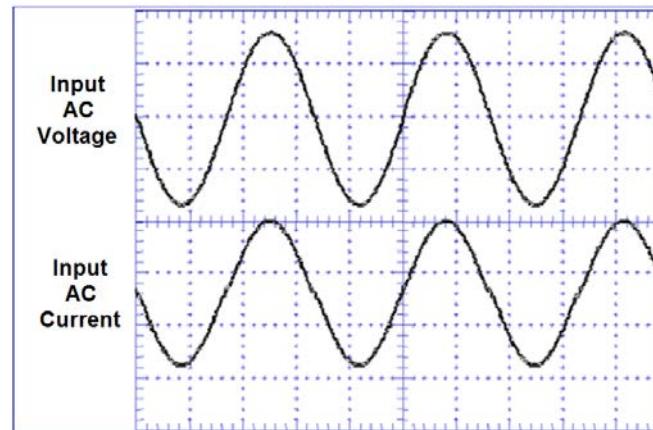
- **Power Factor**

- Power factor is a characteristic of AC circuits only
- Power Factor = Real Power (W) / Apparent Power (V x A)
- If both voltage and current are sinusoidal, it is also equal to the absolute value of the cosine of the phase angle between the voltage and current

Power Supply Common Terminologies

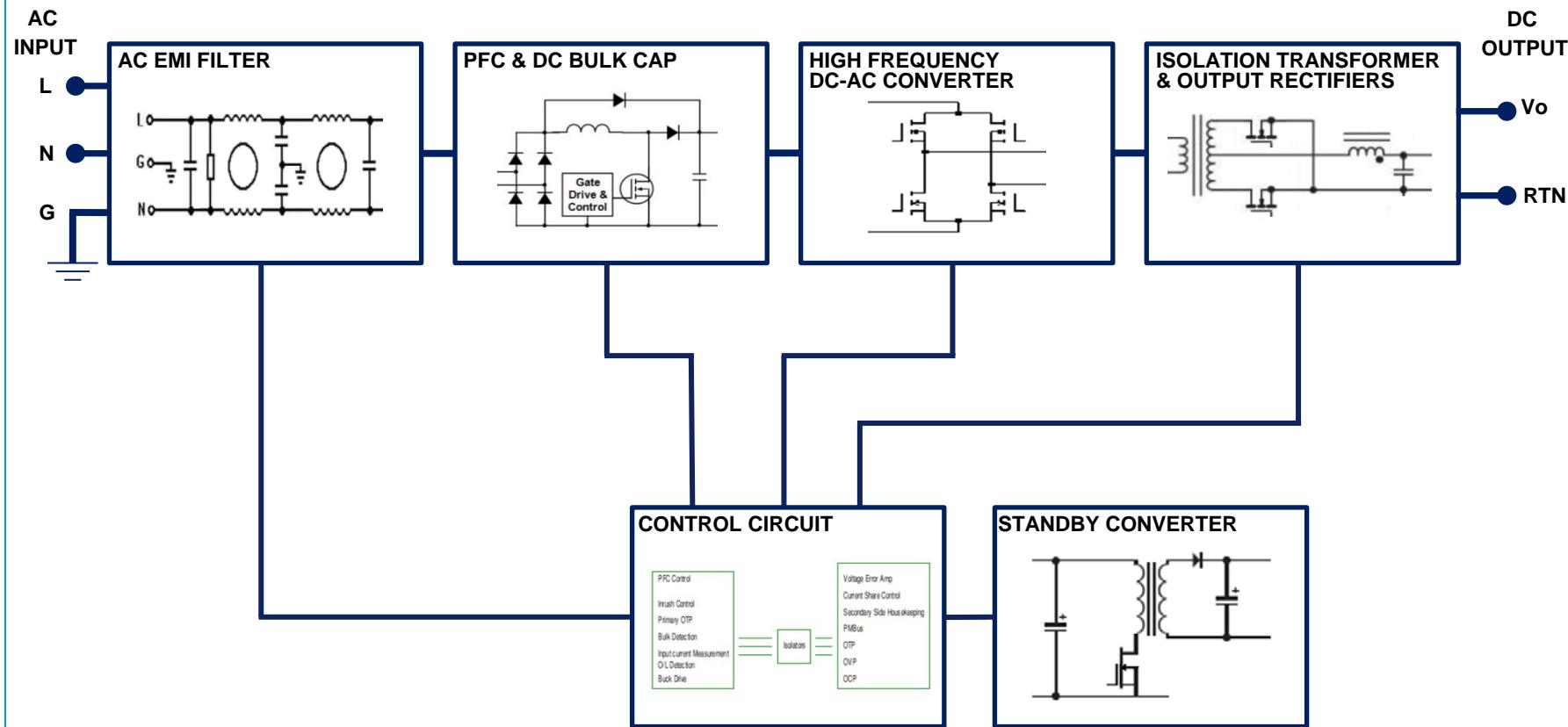
● Power Factor Correction

- PFC (power factor correction) is a feature included in some power supplies where a portion of the circuitry is dedicated to "correct" the power factor by making the current follows the voltage waveform.
- Without PFC, the input current of an AC-DC power supply usually occurs in pulse at the peak of the AC voltage.
- With a PFC circuitry, the input current is shaped to follow the input voltage waveform so the PF is close to unity.



AC/DC Power Supply Block Diagram

- Typical AC-DC Power Supply Block Diagram



Output Load Characteristic

- **Resistive Load**

- Output current is proportional to the output voltage
- Voltage and current ramp up and ramp down together
- Stable control loop
- Output power can be controlled by adjusting output voltage
- Application such as heating elements for precision temperature control

Output Load Characteristic

- **Capacitive Load**

- Larger capacitance connected at the output
- Ability for supporting larger surge / change of output current without cause significant change in output voltage
- Typical use for ripple / noise filtering or larger energy storage
- Starting up will be into a short circuit as output capacitance is discharged – require current limiting / constant current during start up
- Low ESR/ESL of the output capacitors can affect the control loop of the power supply
- Application examples such as charging super cap / ultra cap for power hold up

Output Load Characteristic

- **Inductive Load**

- Typical application is motor or magnetic coil
- Load can become regenerative and cause high back EMF to the power supply output
- Care must be taken to ensure control loop of the power supply is stable under all conditions and the use of sense line is generally not recommended
- Motor load start up will also cause high surge current during motor speed ramp up that can last up to a few seconds or longer and requires the power supply to handle or limit the output current while the motor is ramping up
- Application examples such as robotic machines and medical magnetic imaging systems

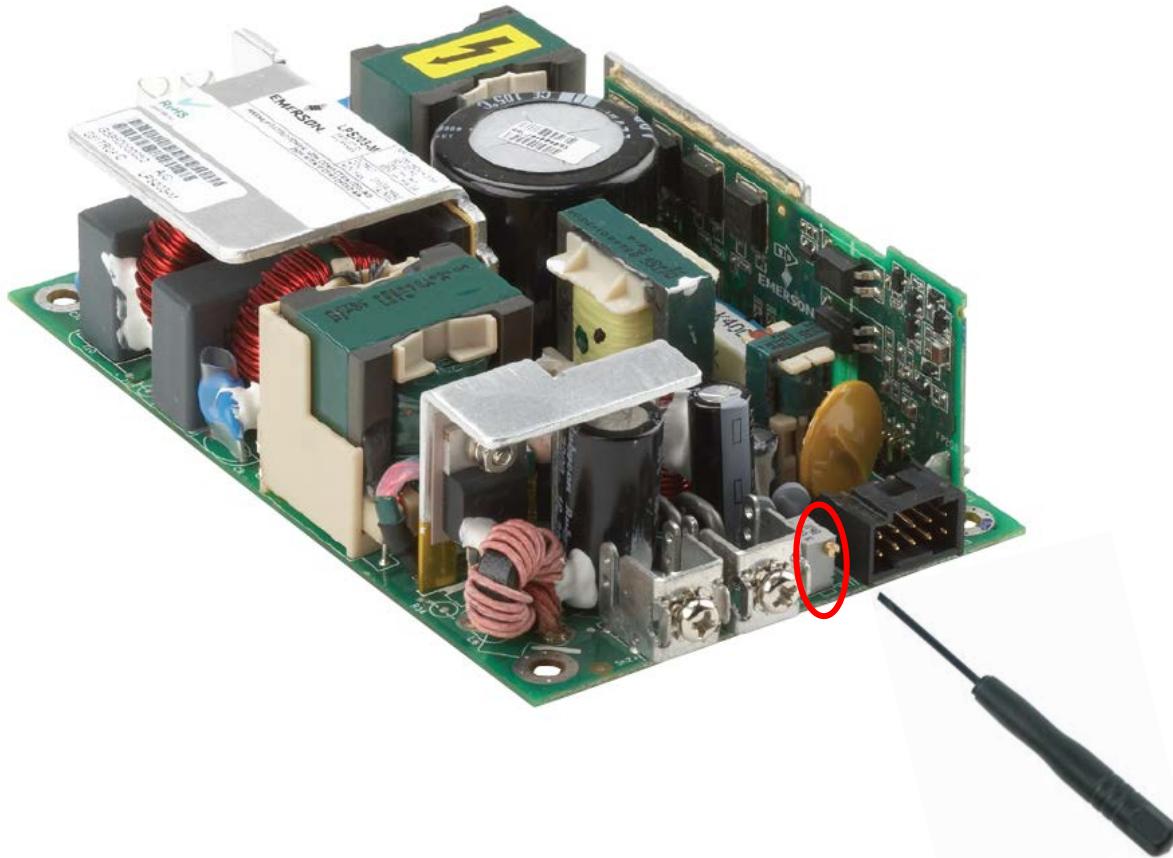
Output Load Characteristic

● DC-DC Converter Load

- Higher voltage buses (48V, 24V or 12V) that power other isolated or non-isolated (POL) converters that power IC's, ASIC's and other electronic circuits
- Load characteristic is predominantly constant power – higher voltage / lower current; lower voltage / higher current
- Care needs to be taken during start up to ensure the DC-DC converters do not start up too early and draw too high of current from the power supply
- Application examples such as computer server, data communication system and all kinds of electronic system

Output Voltage Setting and Adjustment

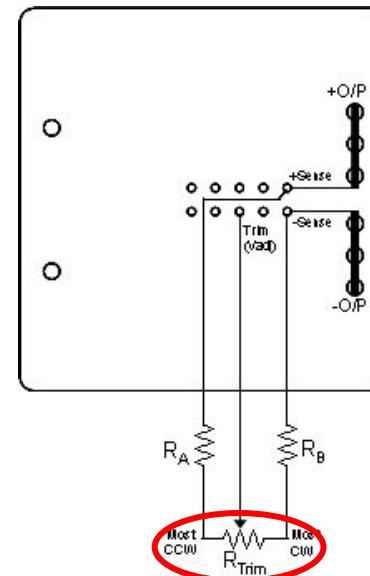
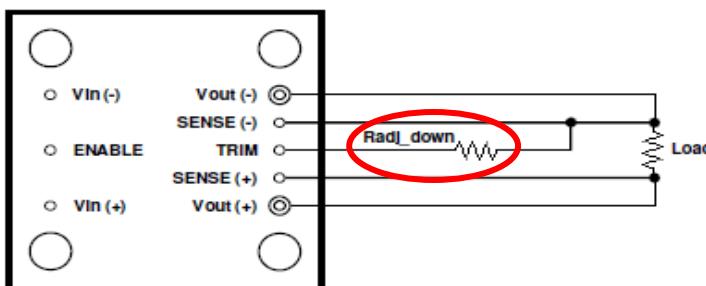
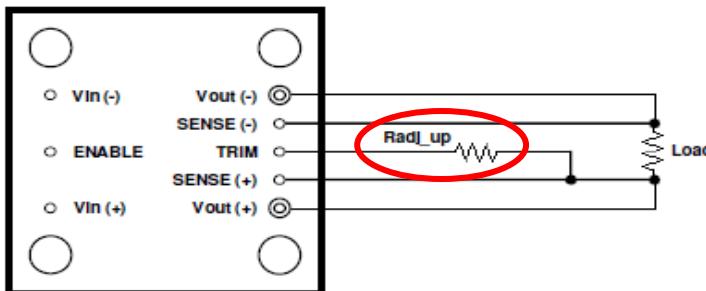
- By Internal Trim Pot



Output Voltage Setting and Adjustment

- By External Trim Resistor and Trim Pot

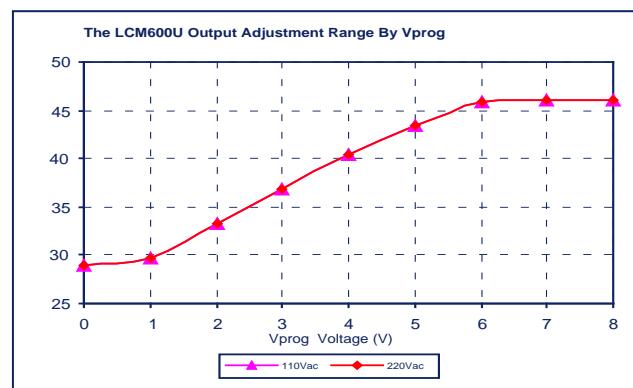
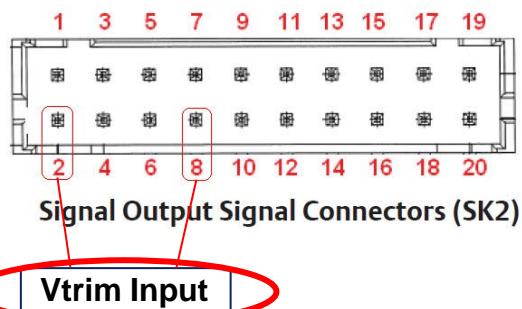
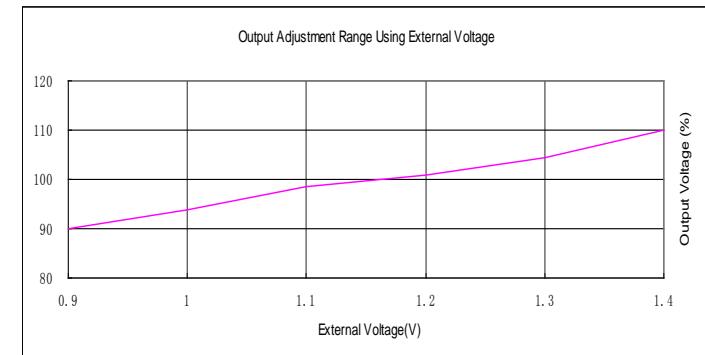
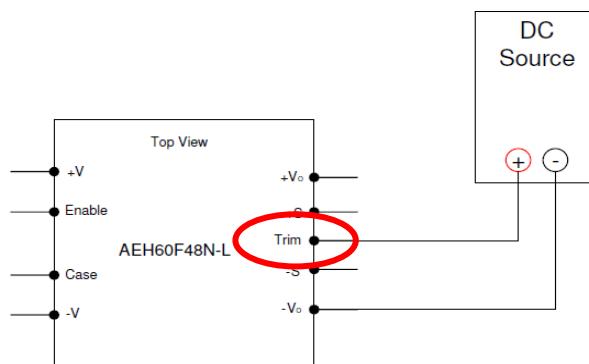
- The output voltage of most power supplies with Trim or Vadj function can be adjusted using a potentiometer (trim pot) by connecting the ends of the potentiometer to the +/-output (or +/-sense pins) and connecting the wiper of the potentiometer to the Trim (Vadj) input of the DC-DC module.



Output Voltage Setting and Adjustment

- **By Trim Input Using External Trim Voltage**

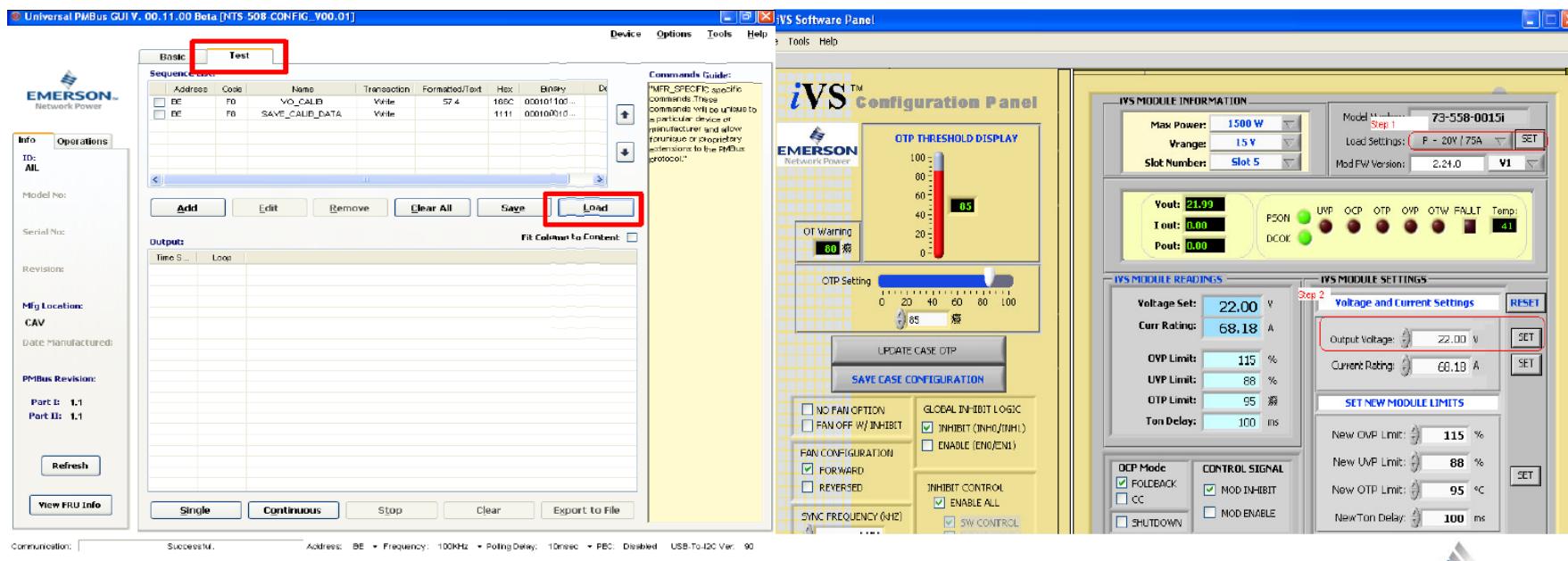
- The output voltage can be adjusted by adding external trim voltage between trim and –sense or -Vo



Output Voltage Setting and Adjustment

● By PMBus Command

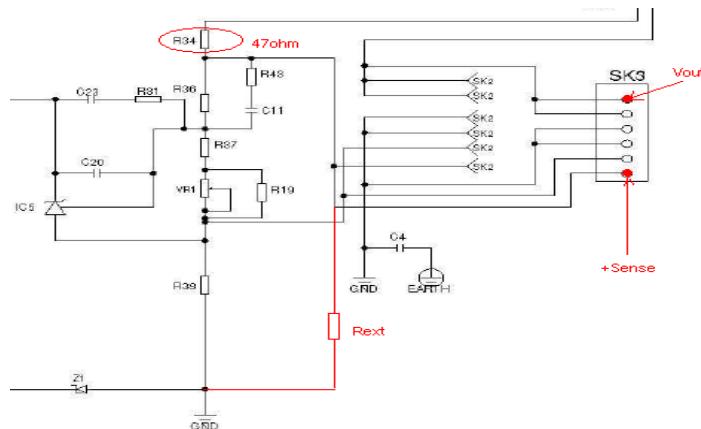
- For products that support PMBus function, output voltage can be adjusted using “VOUT_COMMAND”.
- For configurable products, Graphical User Interface (GUI) supports the adjustment of the output voltage.



Output Voltage Setting and Adjustment

- By Sense Input (Example Emerson LPS53)

- Connect a resistor from +12V output to +sense (an internal 47 ohm resistor already existed) and another resistor from +sense to output Common to form a voltage divider.
- “Desired Vo”= “Nom Vo” * (Rext + 47) / Rext

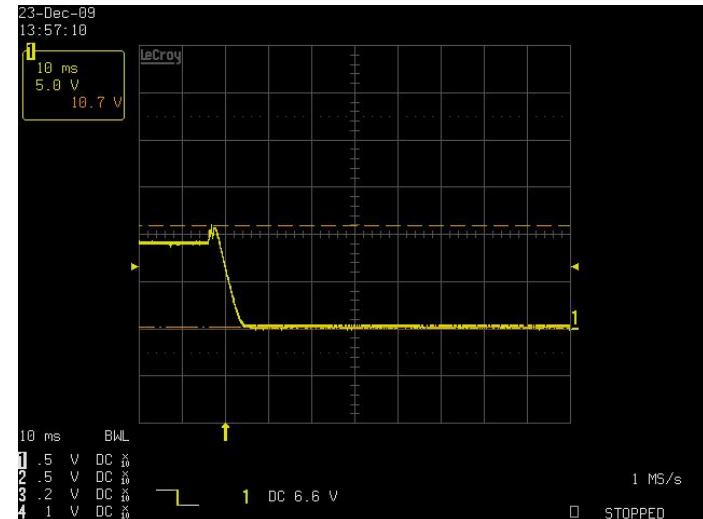
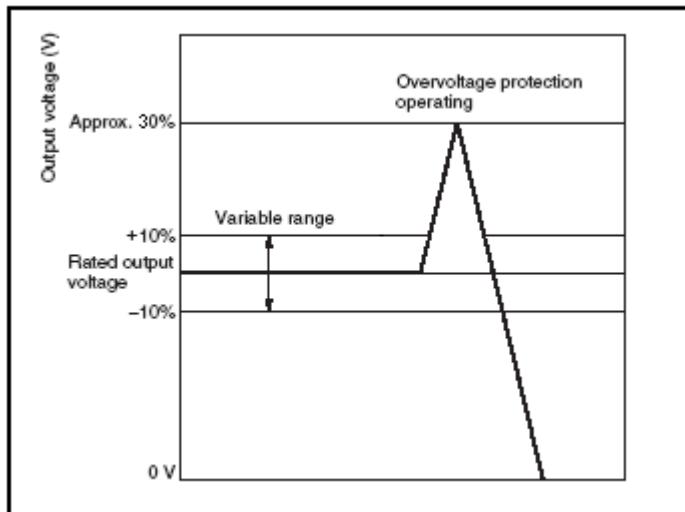


Note:

1. Care should be taken as the sense input is designed for line drop compensation and is connected internally directly to the voltage feedback error amplifier so is sensitive to any external noise or impedance that affect its compensation loop stability.
2. The “Desired Vo” has to be higher than “Nom Vo” and should not be more than by 0.5V

Over Voltage Protection

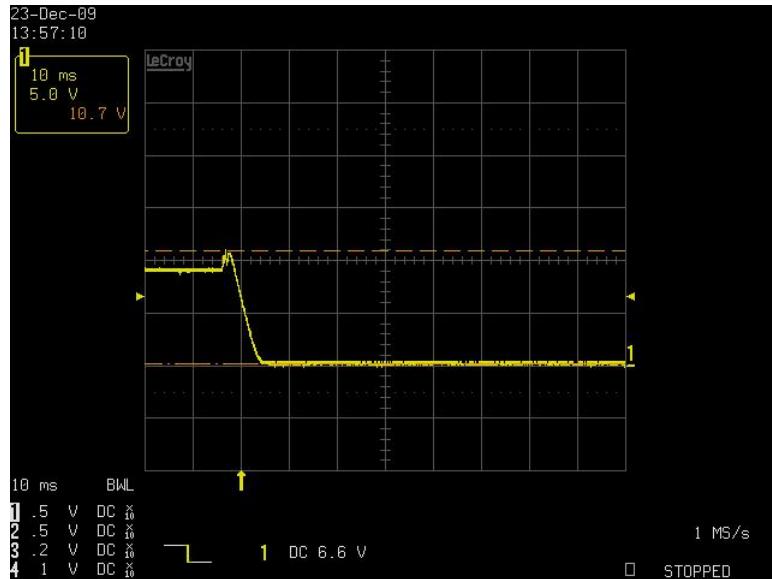
- **What is OVP? (Over Voltage Protection)**
 - A power supply function to protect its load circuit by shutting down the power supply, or crowbars/clamps the output, when the output voltage exceeds a preset level



Over Voltage Protection

- **OVP Modes**

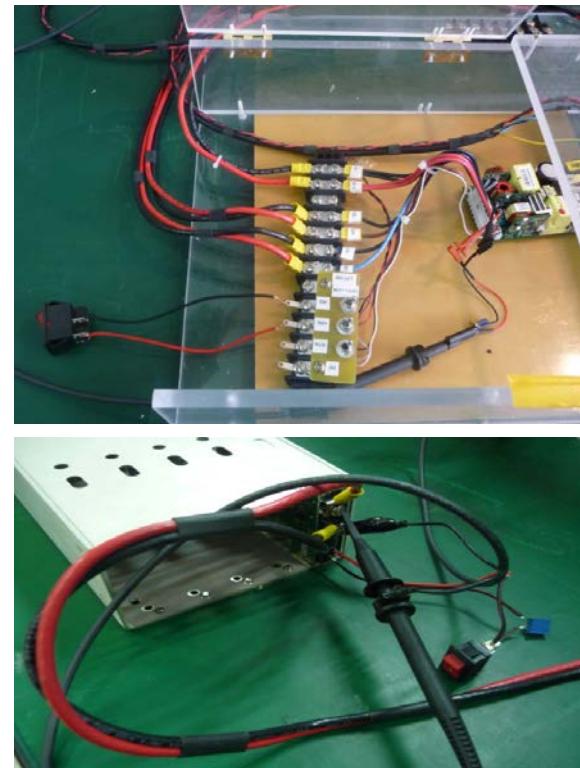
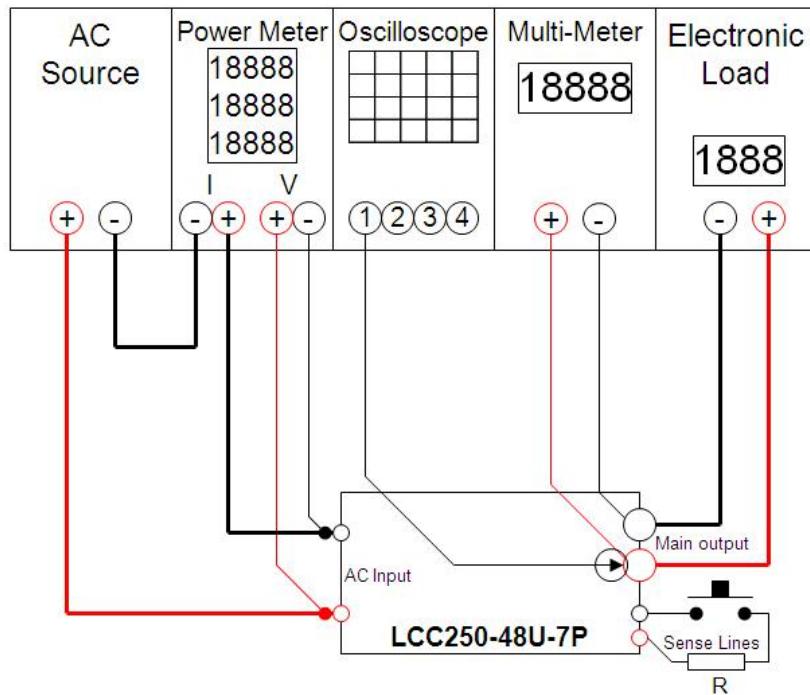
- Latch mode - Shutdown the output voltage and remain off until the power supply is reset by turning it OFF for several seconds and then back ON again.



Over Voltage Protection

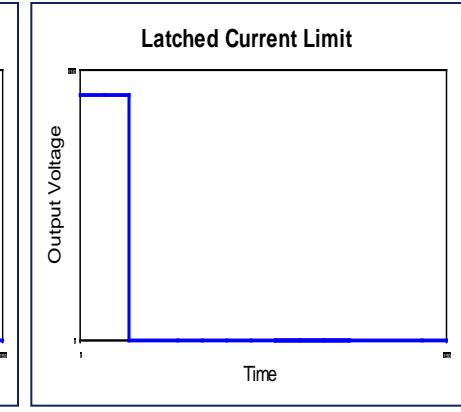
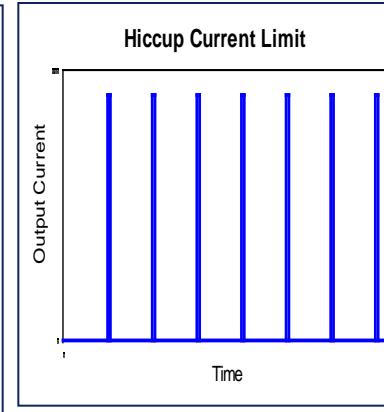
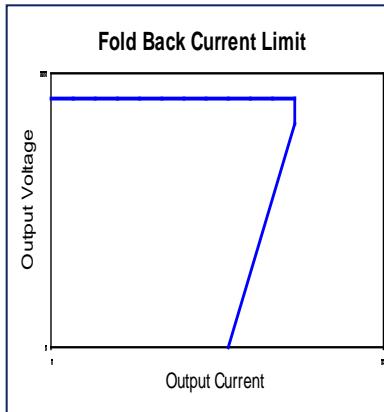
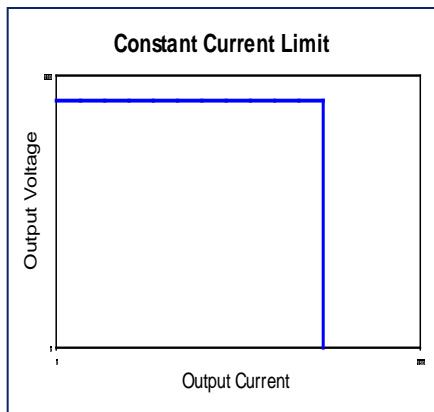
- **Measurement Technique**

- Output Over Voltage Protection can be simulated by shorting the sense lines together which will cause the output voltage to rise and will trigger the Over Voltage Protection when it reaches its threshold point.



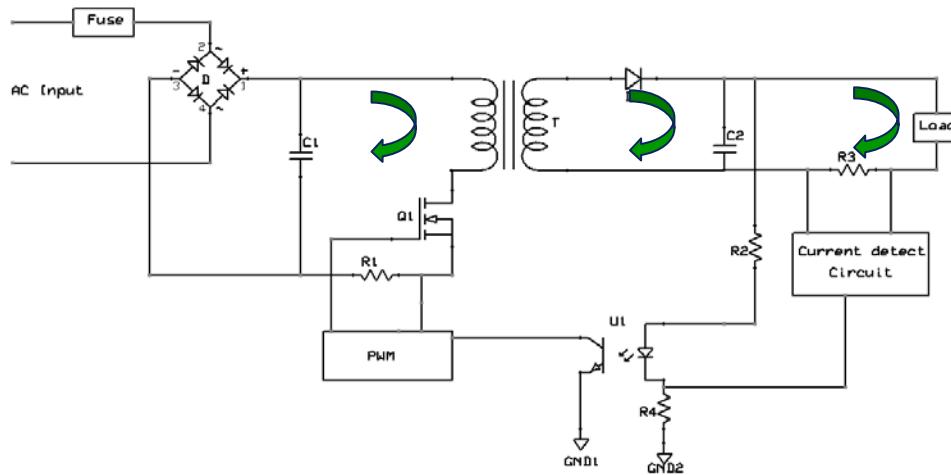
Over Current Protection

- Constant Current Limit
- Fold Back Current Limit
- Hiccup Current Limit
- Latched Current Limit



Over Current Protection

- **Difference Between Primary and Secondary OCP**
 - Primary OCP – Control is in primary side, current signal feedback from secondary to primary through isolation device
 - i.e: LP series, iMP/iVS

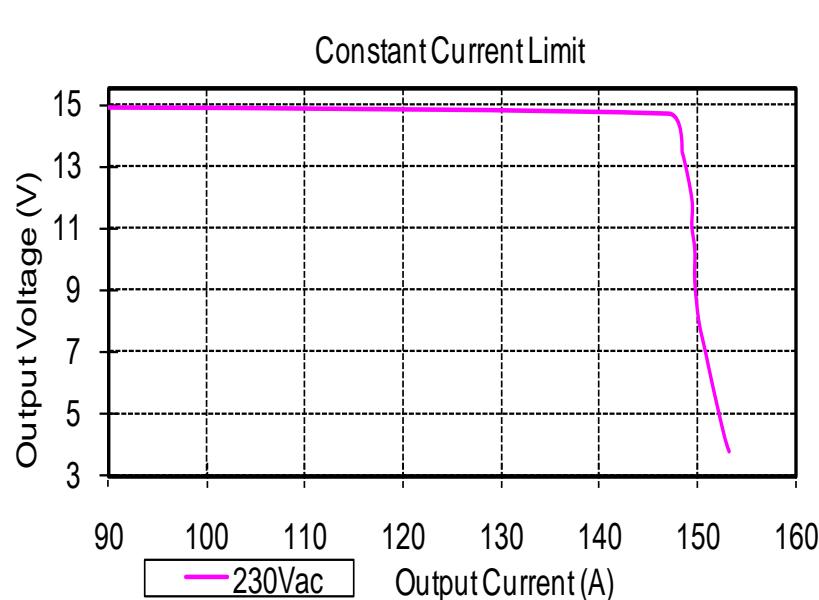


- Secondary OCP – control is in secondary, feedback is direct
- i.e: LDS series, uMP

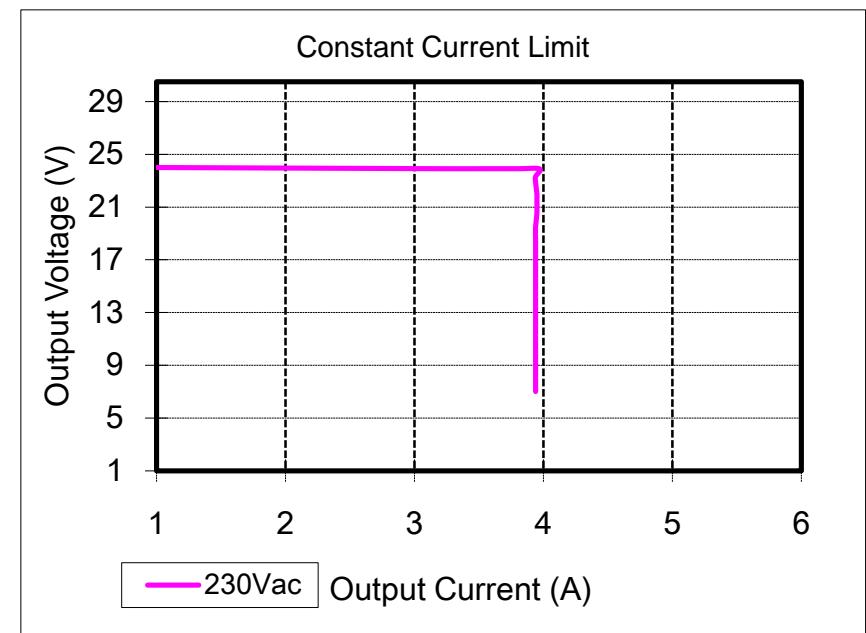
Over Current Protection

- Actual OCP Results:

iVS – Primary OCP

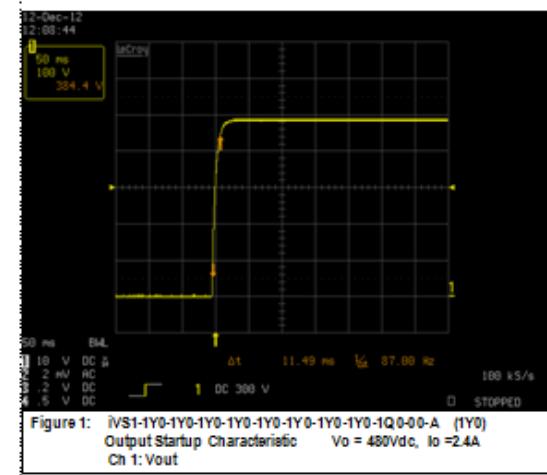
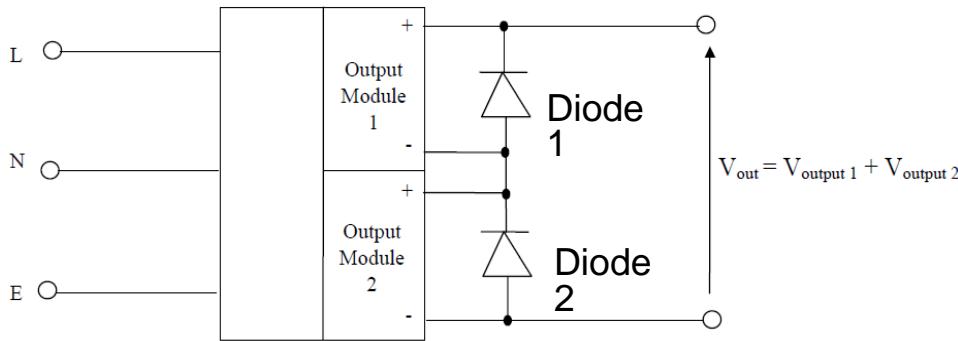


LDS-100 – Secondary OCP



Connect Power Supply Outputs in Series

- Connect power supply outputs in series to obtain higher output voltage

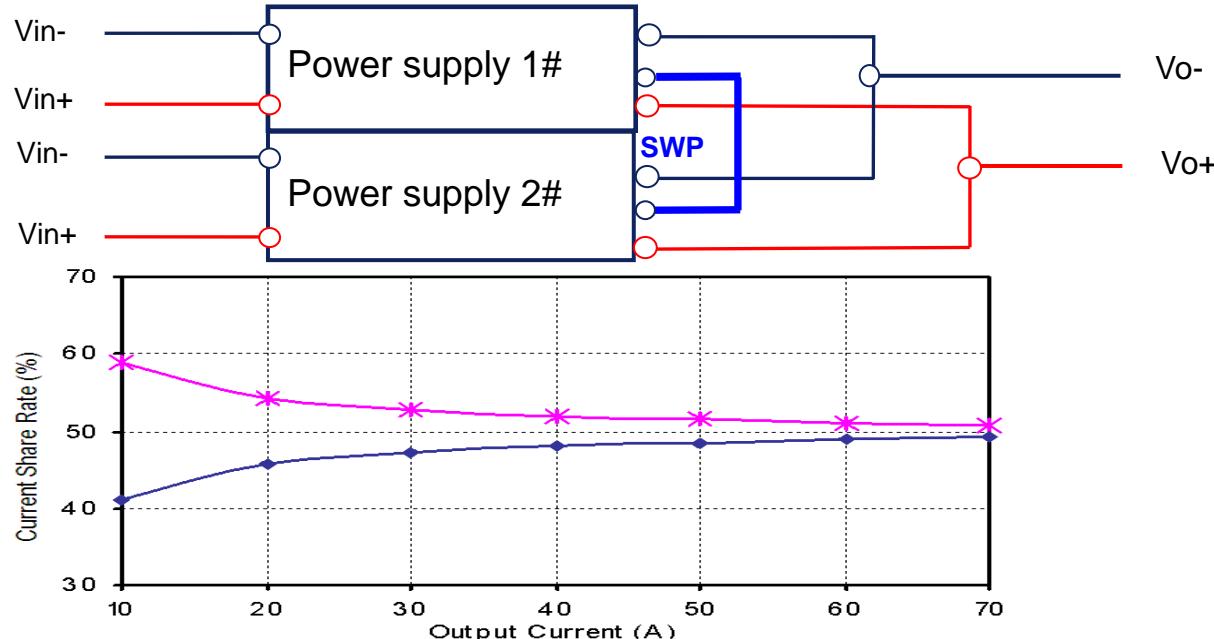


- In order to ensure that no module output experiences reverse voltages caused by differences between modules during start-up, diodes must be connected across each module, as shown in the schematic above.
- Total output voltage must be less than each output's Y-cap withstand voltage value

Connect Power Supply Outputs in Parallel

• Active Current Share – SWP

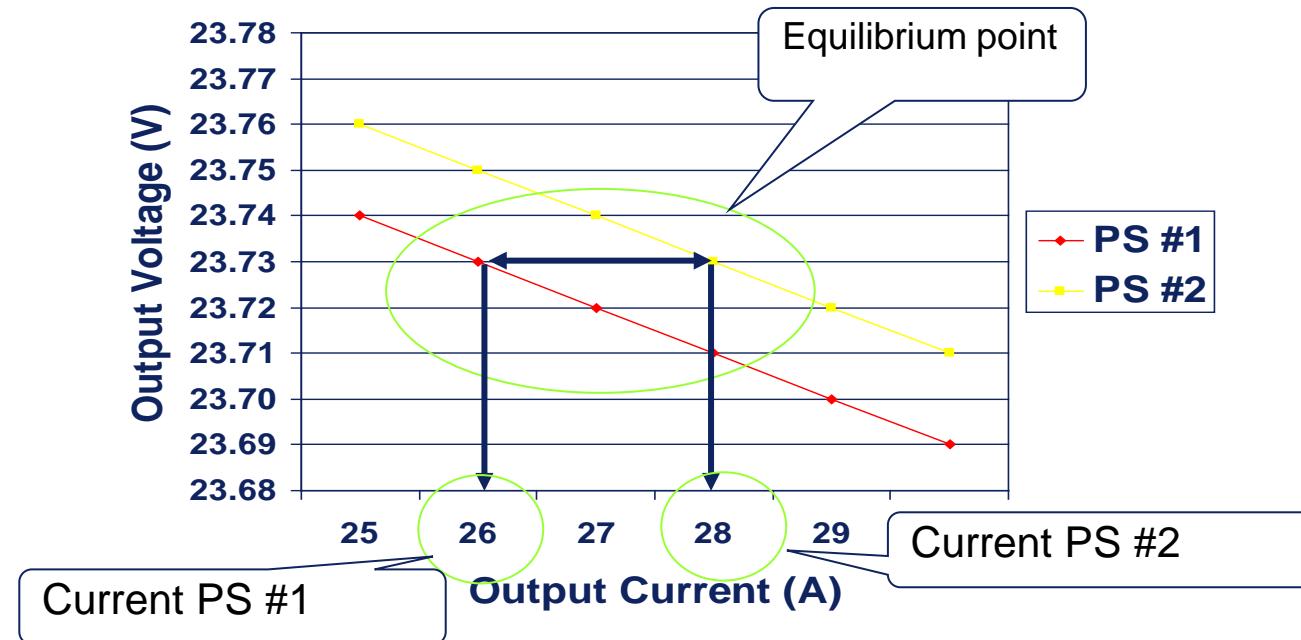
- This current share method relies upon each power supply unit to provide a signal that is proportional to its output current on its SWP pin. Since the SWP pins of all power supply units are connected together, this signal will get averaged or or'ed.
- Each power supply unit will then compare this averaged/or'ed SWP signal to its internal reference current signal and correct its output voltage accordingly.



Connect Power Supply Outputs in Parallel

- **Droop Current Share**

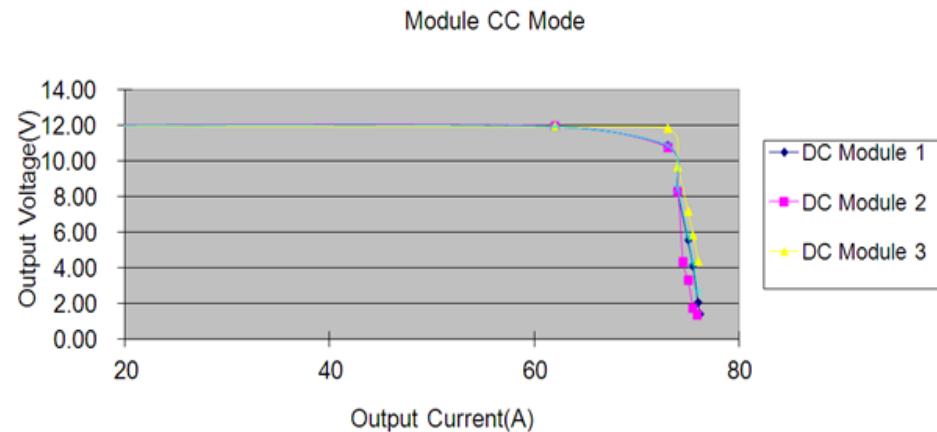
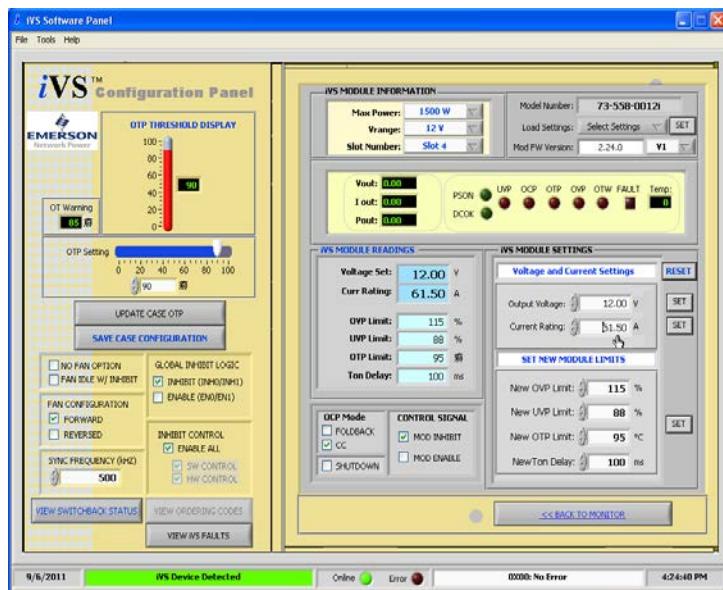
- When the output current of one power supply increases, its output voltage slightly decreases, this forces the other supplies to take more current. If all supplies are adjusted to the same voltage at a given load and have the same voltage versus current slope, they will share the load with high accuracy.



Connect Power Supply Outputs in Parallel

Constant Current Mode Sharing

- Constant current will share current naturally without the need of connecting any SWP. This is because each power supply is in current limit and providing the set constant current value. So as long as they operate in constant current mode, they will share the load current according to their set constant current characteristic curve. Take iVS1-5L2-5L2-61-A as example:



Series Lines

- **When and How to Connect the Sense Lines:**

- Use of the “Remote Sense” is to compensate for the voltage drop on long leads or wire connections.
- Recommend using twisted pair of wires to connect the remote sense leads directly to the +Load and -Load terminals. The remote sense leads carry very little current, so light gauge wires can be used.

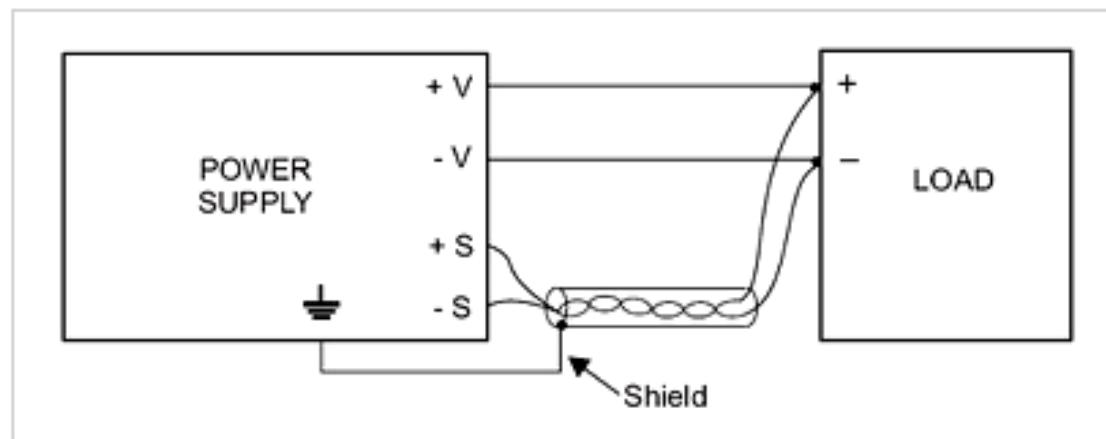
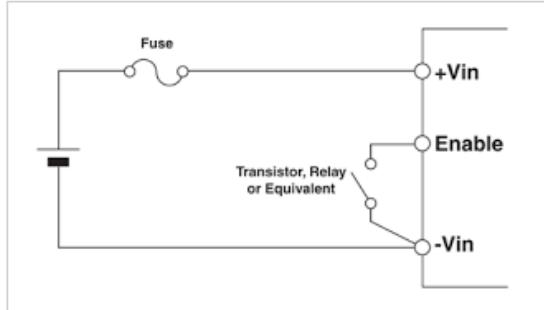


Fig. 1: Power Supply with Remote Sense Wires Connected at the Load

Inhibit / Enable Control

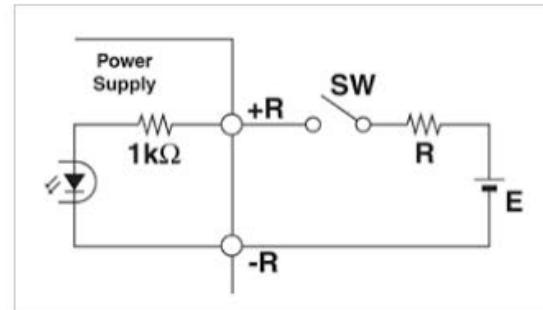
- Inhibit - to turn off the output voltage
- Enable - to turn on the output voltage
- Use of the Inhibit / Enable control function
 - Turn on/off output at command
 - Output voltage sequencing
 - Faster response
- Interface

Internal biased



short to GND to enable

Isolated

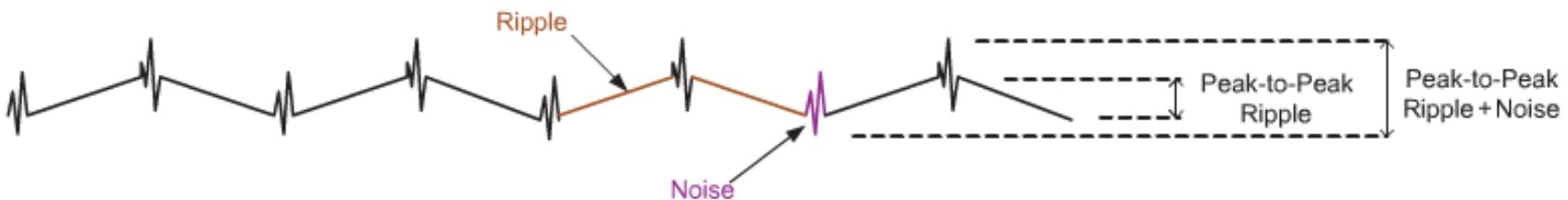


require external power source



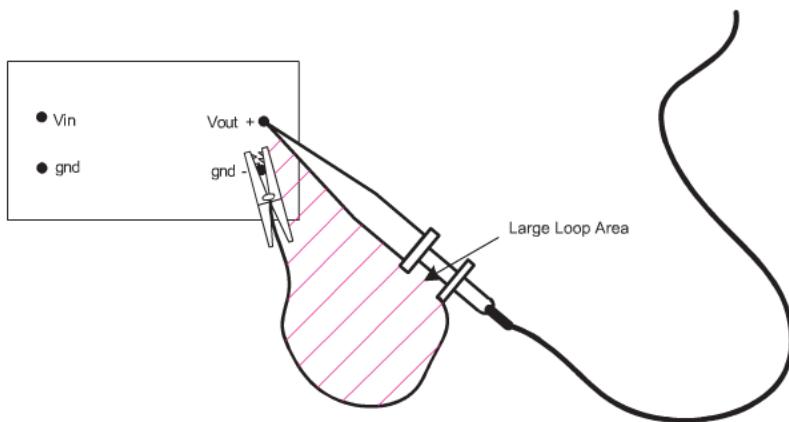
Output Ripple Reduction Techniques

- **Ripple:**
 - Caused by energy transfer at each switching cycle.
 - Ripple frequency is the same as the converter switching frequency and some multiple thereof.
- **Noise:**
 - Caused by ringing in parasitic inductances from larger di/dt .
 - The noise is of much higher frequency than the ripple and can be up into the MHz range.
 - Noise occurs in the form of “bursts” at the time of switching activity in the converter, so therefore appears to be superimposed upon the peaks and valleys of the ripple waveform.

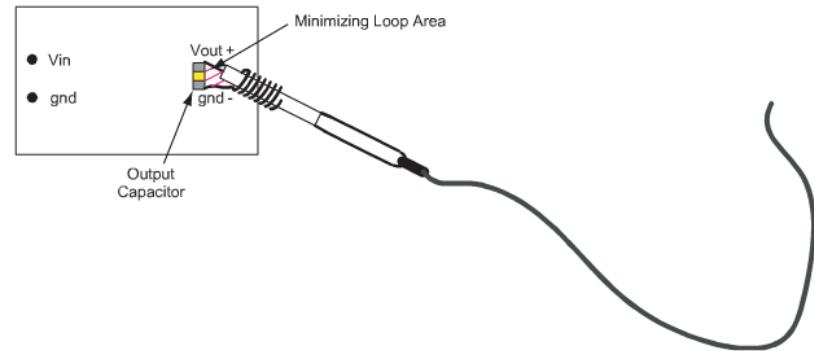


Output Ripple Reduction Techniques

- How to Test the Ripple and Noise:



Incorrect method



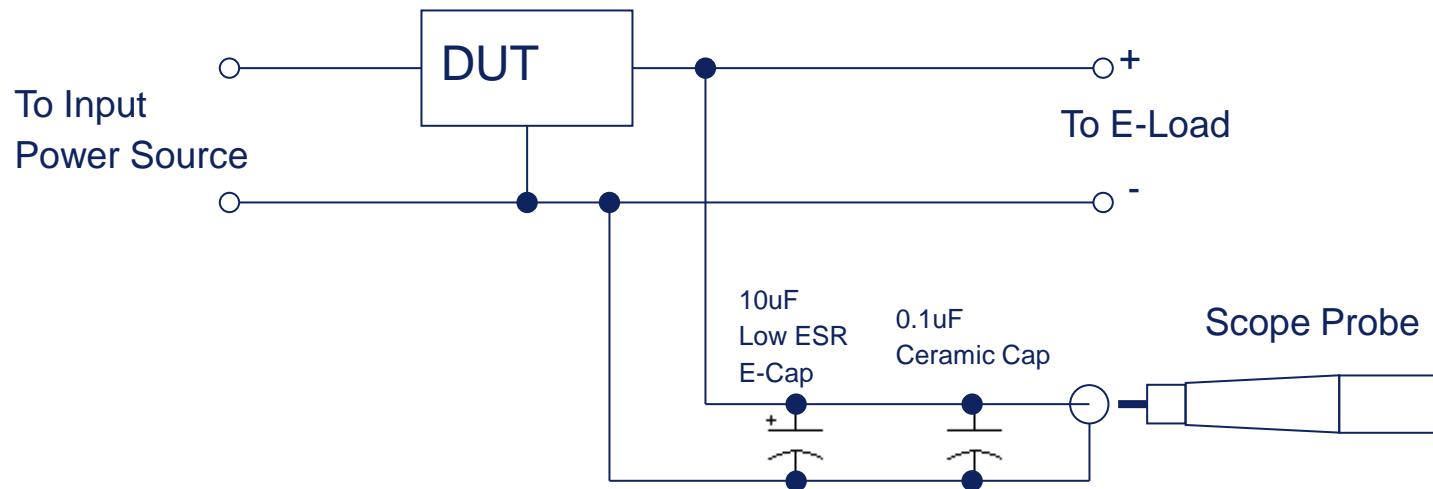
Correct method

Why - The scope probe GND lead can pick up radiated noise

Output Ripple Reduction Techniques

- **Measurement Technique**

- When measuring output ripple and noise, a scope jack in parallel with a 0.1uF ceramic chip capacitor, and a 10uF low ESR electrolytic capacitor should be used. Oscilloscope should be set to 20 MHz bandwidth for this measurement



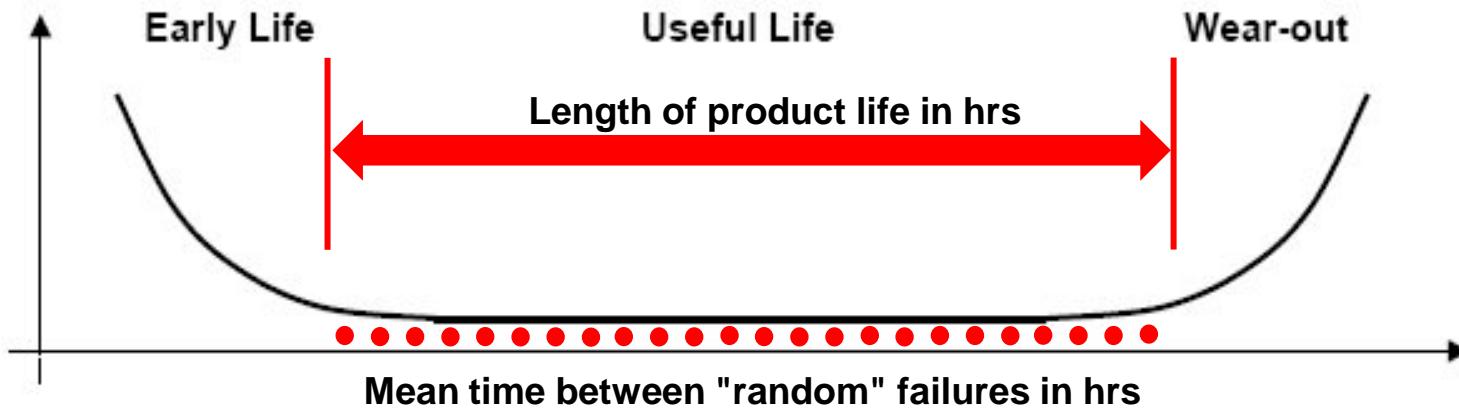
Output Ripple Reduction Techniques

- **How to Reduce the Ripple and Noise**

- Start with a power supply with low ripple and noise
- Add small low ESR cap at both power supply and load end for noise reduction
- Add larger filter cap at load end to reduce ripple
- Keep output +ve and –ve tightly couple to reduce noise pickup
- Add low-pass filter if very low ripple is required
 - To add low pass filter, sense lines should be connected before the filter to avoid oscillation or not use remote sense at all
 - Keep inductance small
 - Use high quality filter capacitors

LIFE vs MTBF

- "Product life" and "MTBF" of a product:
 - Both measured in "hrs" but are quite different in what they measure
 - "Product life" measures the length of the useful life of a product before some wear out condition takes over and causes the end of life
 - "MTBF" measures the mean time between "random" failures in a batch of products during the "useful life" portion of the "bath tub" curve.



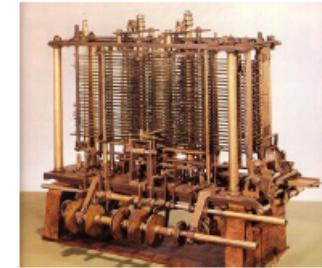
LIFE vs MTBF

- "Life" and "MTBF" are two different unrelated measurements.
- "MTBF" is a reliability measurement - the expected failure rate of a batch of product in operation.
- "Life" is not a reliability measurement - it is a design specification to determine when a product should be replaced.

Intelligent Control: History

Power Control

- 1965 First patent showing a “digital computer” used to regulate current in a circuit
- 1990’s digital control used in UPS’s and large AC/DC supplies
- Early 2000’s DSP used for power conversion
- 2002-5 State machines allow for low cost POL



Power Management

- Early 1980’s digital control of power systems in telephone central offices and across phone networks
- Late 1980’s digital control of large computers (e.g. DEC VAX 9000)
- Mid 1990’s digital control in desktop and notebook computers (SMBus)
- 2001 Introduction of digital power management controllers
- 2004 Introduction of power management bus (Z-bus, PMBus)

Courtesy of Chris Young, Sr. Manager, Intersil Zilker labs

Power Control + Power Management = **Digital Power**



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Intelligent Control: Different Schemes

Digitally Assisted Analog Control

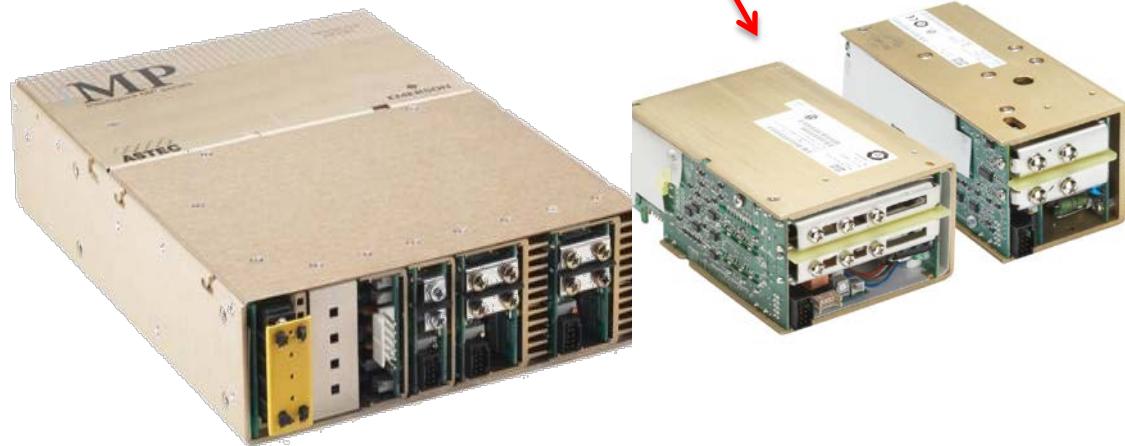


Digital Power: Bringing you flexibility today
and innovation tomorrow...

Redefining the word flexibility, Astec Power's new Intelligent MP Series provides innovative full I²C control, integrated within a medically approved high density RoHS compliant modular power supply system. The award-winning *iMP* offers up to 50% higher power density with no increase in cost over the existing industry leading MP series. With over 200 million standard combinations and flexible customer programmable features, the *iMP* is truly ahead of its time.

Intelligent Control: Different Schemes

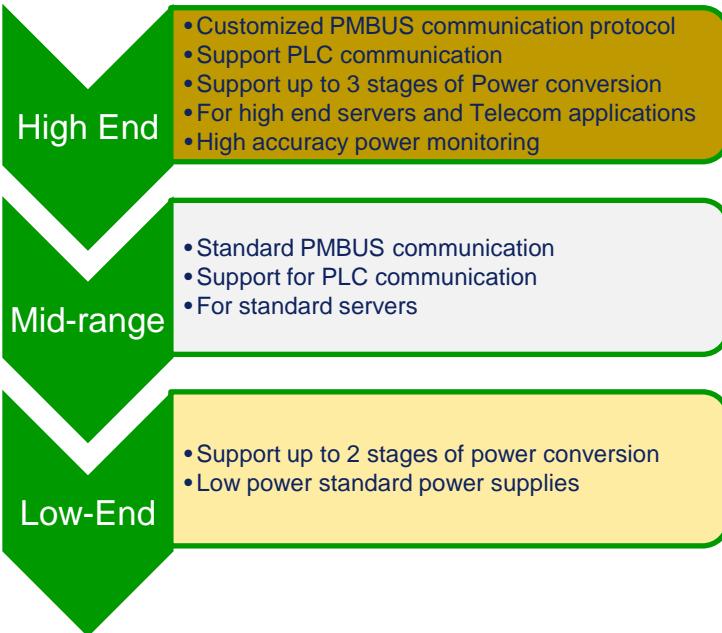
Software Managed Hardware Implemented Digital Control



Emerson iMP/iVS - 750W / 1500W modules

Intelligent Control: Different Schemes

Fully Software Executed Control



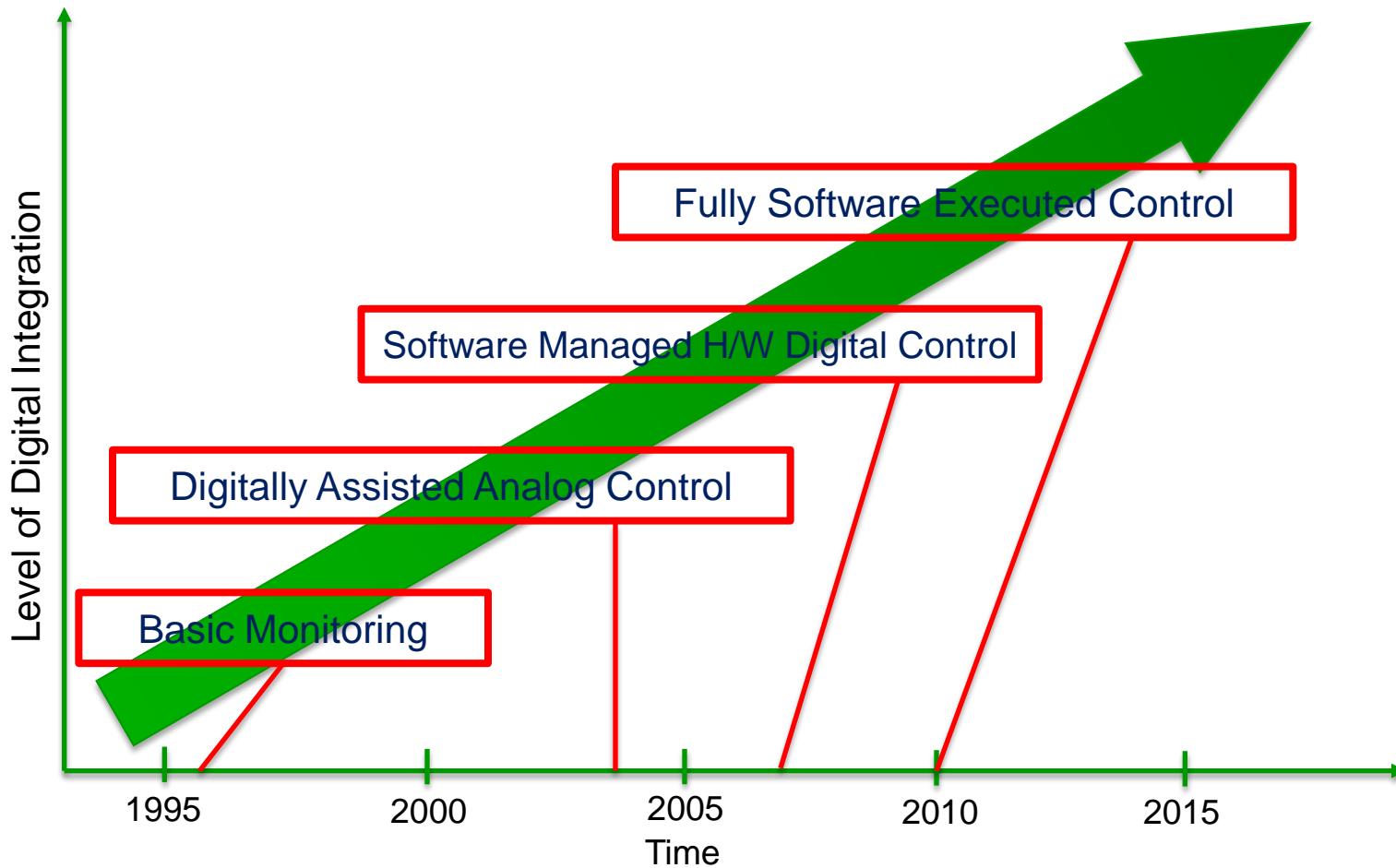
After leading edge server power solutions, we have an aggressive plan of extending digital power technology to all power conversion applications

Standard Low Power
Medium Power



Since 2013, all Emerson new power supply designs are using digital control

Intelligent Control: Different Schemes



Intelligent Control – Examples



Bulk Front End – HPS



500W – NTS500 Series



Medium / High Power: iVS & iMP Configurable Power Supplies

Configurable Power Supplies

- Specification flexibility with no NRE, bridge to customs
- Safety approved
- Building Block Approach
- Standardized Footprint
- Design Leverage – Low Risk
- Feature Rich
- Easy to Modify
- Fast Time To Market
- Single Solution for Multiple System Configurations
- Volume Cost Leverage



Configurable Power Supplies – Examples

- Emerson intelligent iMP Series

Intelligent MP Series

*Intelligent modular power supply
for optimum flexibility*

Up to 1500 Watts

Total Power: Up to 1500 Watts

Input Voltage: 85-264 Vac
120-300 Vdc

of Outputs: Up to 21

iMP®



Special Features

- Full Medical EN60601 approval
- Intelligent I²C control
- Voltage adjustment on all outputs (Manual or I²C)
- Configurable input and output (case and module) OK signals and indicators
- Configurable inhibit/enable
- Configurable output UP/DOWN sequencing
- Configurable current limit (foldback or constant current)
- High power density (8.8 W/cu-in)
- Intelligent fan (speed control/fault status)
- Downloadable GUI from website
- Customer provided air option
- μP controlled PFC input with active inrush protection
- I²C monitor of voltage, current and temp
- Programmable voltage, current limit, inhibit/enable through I²C
- Optional extended hold-up module (SEMI F47 compliance)
- CAN BUS and RS-485 interface option
- Low leakage (<300 μA)
- Increased power density to 50% over standard MP
- Backward compatibility with standard MP
- External switching frequency sync input
- Optional conformal coating
- Industrial temp range (-40 °C to 70 °C)
- No preload required
- Industrial shock/vibration (>50 G's)



Configurable Power Supplies – Examples

- Emerson intelligent iMP Series

Convenient Range of PFC Front Ends Cases

Three Case Sizes

iMP4 - 750 -1100W - 2.5"x5"x10" (5 slots)

iMP8 - 1000 -1200W - 2.5"x7"x10" (6 slots)

iMP1 - 1200 -1500W - 2.5"x8"x11" (7 slots)



Single



210 W



750 W



360 W



1500 W



144 W



36 W

Wide Selection of DC/DC Output Modules

Six Output Module Types

1500W - Single Output - 1.8 - 60V, 300A (4 slots)

750W - Single Output - 1.8 - 60V, 150A (3 slots)

360W - Single Output - 1.8 - 60V, 60A (2 slots)

210W - Single Output - 1.8 - 60V, 35A (1 slot)

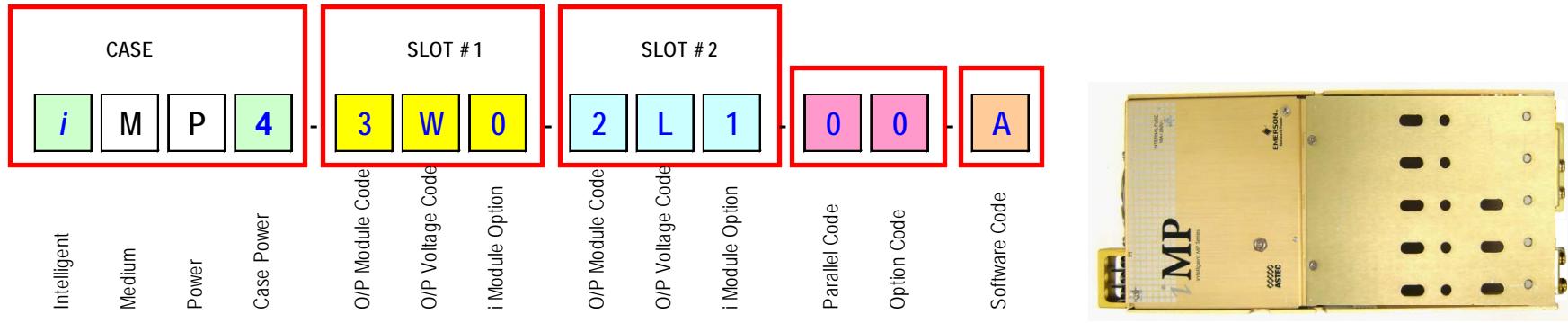
144W - Dual Output - 1.8 - 28V, 10A (1 slot)

36W - Triple Output - 1.8 - 28V, 2A (1 slot)

OVER 200 MILLION COMBINATIONS

Configurable Power Supplies – Examples

- iMP4 Construction Example:
-1100W power supply with two outputs - 48V/15.6A, 12V/30A



Case Code Standard

4 = 5 slot, 400-600W
6 = 6 slot, 600-800W
8 = 6 slot, 800-1000W
1 = 7 slot, 1000-1200W

Case Code Intelligent

4 = 5"x10", 5 slot, 750-1100W
8 = 7"x10", 6 slot, 1000-1200W
1 = 8"x11", 7 slot, 1200-1500W

Software Code

A - Standard

O/P Module Code

1 = 210 W Single 1 Slot
2 = 360 W Single 2 Slot
3 = 600 W / 750W Single 3 Slot
4 = 144 W Dual 1 Slot
5 = 1500W Single 4 Slot
_ = 36 W Triple 1 Slot

O/P Voltage Code

A=2V N=15V
B=2.2V O=18V
C=3V P=20V
D=3.3V Q=24V
E=5V R=28V
F=5.2V S=30V
G=5.5V T=33V
H=6V U=36V
I=8V V=42V
J=10V W=48V
K=11V X=54V
L=12V Y=60V

Parallel Code

0 = no parallel
1 = slots 1 & 2
2 = slots 2 & 3
3 = slots 3 & 4
4 = slots 4 & 5
5 = slots 3 & 4 & 5
6 = slots 5 & 6
7 = slots 4, 5 & 6

i Module Option
0 = Standard
1 = Module Enable

Option Code

0 = no options
1 = Reverse Air
3 = Global Enable
4 = Fan off with Inhibit
5 = opt 1 & 3
6 = opt 1 & 4
7 = opt 3 & 4
8 = opt 1, 3 & 4
9 = Future
M = Low Leakage
N = Low Leakage + opt 1
P = Low Leakage + opt 3
R = Low Leakage + opt 5

Configurable Power Supplies – Examples

- Output Module Ranges:

Output Module Voltage/Current

Voltage	Voltage Code	Single Output Module Code			Dual Output		Triple Output			I ^C Adjustment Ranges
		1	2	3	V1	V2	V1	V2	V3	
2V	A	35A	60A	150A	—	10A	—	—	2A	1.8-6.1
2.2V	B	35A	60A	150A	—	10A	—	—	2A	
3V	C	35A	60A	150A	—	10A	—	—	2A	
3.3V	D	35A	60A	150A	—	10A	—	—	2A	
5V	E	35A	60A	150A	10A	10A	—	—	2A	
5.2V	F	35A	60A	150A	—	10A	—	—	2A	
5.5V	G	34A	58A	137A	—	10A	—	—	2A	
6.0V	H	23A	42A	80A	—	10A	—	—	2A	5.4-13.2
8.0V	I	20A	36A	80A	—	—	1A	1A	1A	
10V	J	18A	32A	75A	—	—	1A	1A	1A	
11V	K	17A	31A	68A	—	—	1A	1A	1A	
12V	L	17A	30A	62.5A	10A	4A	1A	1A	1A	
14V	M	14A	21A	53.5A	9A	4A	1A	1A	1A	12.6-22.0
15V	N	14A	20A	50A	8A	4A	1A	1A	1A	
18V	O	11A	19A	41.6A	—	—	—	0.5A	0.5A	
20V	P	10.5A	18A	37.5A	—	—	—	0.5A	0.5A	
24V	Q	8.5A	15A	31.3A	4A	2A	—	0.5A	0.5A	21.6-39.6
28V	R	6.7A	12.8A	26.8A	3A	2A	—	0.5A	0.5A	
30V	S	6.5A	12A	25A	—	—	—	—	—	
33V	T	6.2A	11A	22.7A	—	—	—	—	—	
36V	U	5.8A	10A	20.8A	—	—	—	—	—	
42V	V	4.2A	7.5A	17.9A	—	—	—	—	—	37.8-60.0
48V	W	4.0A	7.5A	15.6A	—	—	—	—	—	
54V	X	3.7A	6.0A	13.9A	—	—	—	—	—	
60V	Y	3.5A	6.0A	12.5A	—	—	—	—	—	
VOLTAGE CODE		SINGLE OUTPUT		DUAL OUTPUT		TRIPLE OUTPUT				

Field Configurability

- **Programmability on Each Output:**

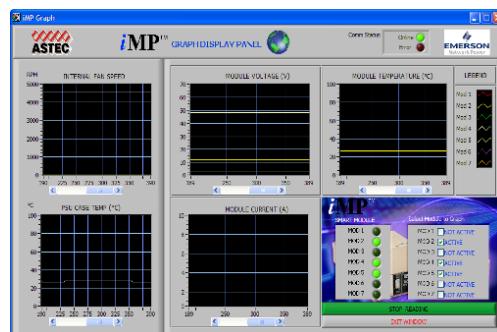
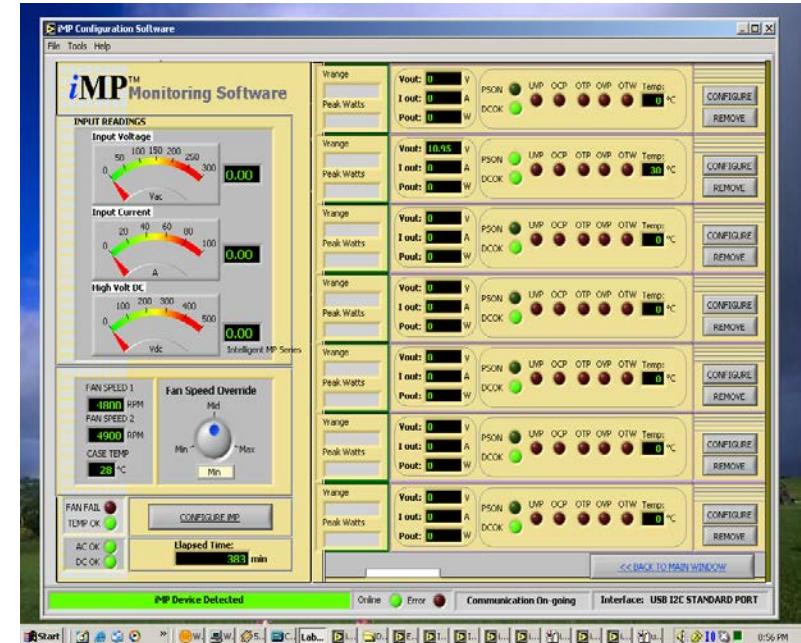
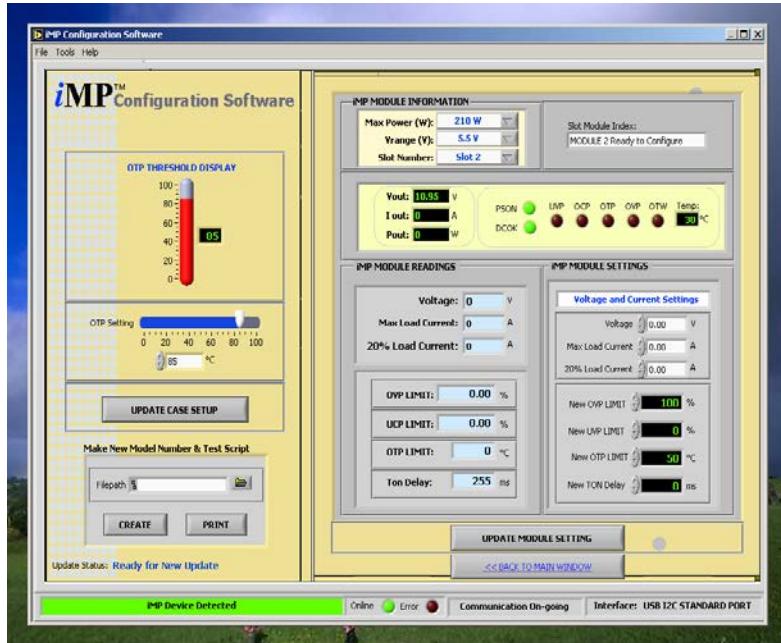
- Output Voltage
- Output Enable/Sequencing
- Output Over-Current Limits
- Module Inhibit/Enable Polarity
- Current Share Profile (Match Competitor)
- Special DCOK Configuration
- External Synchronization of Module Switching Frequency

Field Configurability

- **uP Interface to Case/Modules**
 - Configuration Map/Mfg Time/Date/Wattage
 - Global Inhibit/Enable, Module Sequence
 - Elapse Time Meter
 - Communications Interface
 - PM Bus (I2C) Standard
- **Smart Fan**
 - Variable speed based on Ambient and Load / No Fan option available
 - Fault/Tachometer
- **Parametric Data on Each output**
 - Output Voltage/Current/Temp

Field Configurability

- Field Programming Graphic User Interface (GUI)



Field Configurability

- Universal PMBus GUI
- GUI Designed to Aid Engineers in Development
 - Tool for debugging power supply issues
 - Input thresholds
 - Output settings
 - Delay times
 - Switching frequency
 - Loop response
 - Other parameters...

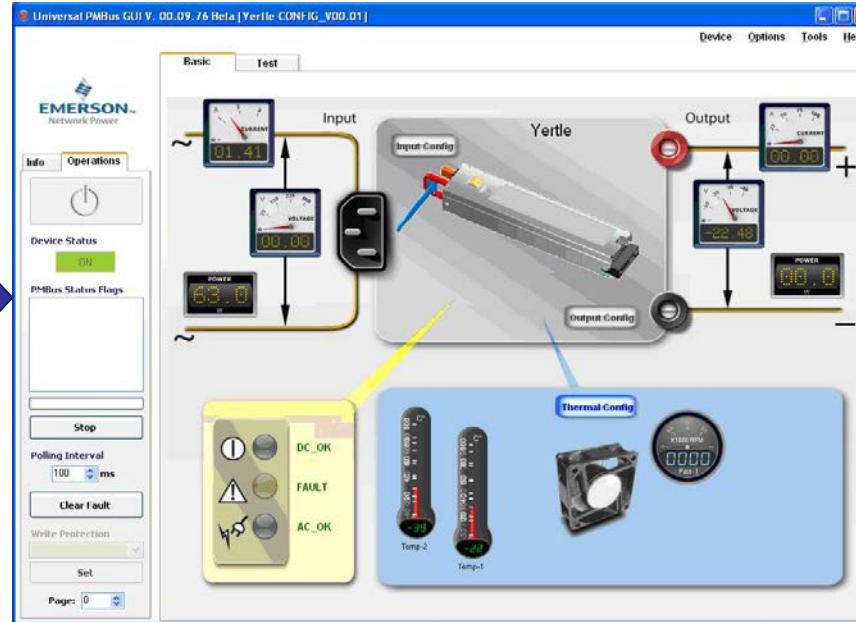


Field Configurability

Universal PMBus GUI

Accurate Monitoring and Reporting Functions

- 1% reporting accuracy of power supply input parameters such as voltage, current, and power
- Allows better system manipulation of itself for optimum efficiency



Failure Prediction

- Ability of the PSU to self-diagnose for potential failures or weakened parts by monitoring and comparing specific parameters against nominal values

History logging

- Event logging of power supply environment conditions such as input voltage surge and sag, AC recycles, maximum ambient and internal temperatures, etc...
- Includes failure logging of up to 10 failure events of PSU to backtrack failures

Low Power Mode

- Reduction of power supply bias consumption during low power consumption levels of the system
- Architecture will not have impact on power availability in the event that the system requires power upsurge

Fan Speed Optimization

- System has the capability to determine fan operating point such that maximum efficiency at specific loads can be attained



Rapid Modification of Standard Power Supply Platforms gets you to market faster

THAT'S THE CRITICAL DIFFERENCE.

A new white paper shows you how to precisely match your power requirements, fast.



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Rapid Modification of Standard Power Supply Platforms maximizes your design flexibility and time to market.

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